AD-A251 989

(2)

FINAL REPORT

U^{3+} SOLID-STATE LASERS

[DIODE-PUMPED SOLID-STATE LASERS (2-3 Microns)]

Contract No. N00014-90-J-4007

Period of Performance: 5/1/90 - 12/31/91

DTIC
ELECTE
JUN 23 1992
S A D

Submitted to

Robert L. Bachman
Department of the Navy
Office of Naval Research
Resident Representative
University of California, San Diego
Scripps Institution of Oceanography, 0234
La Jolla, CA 92093-0234

By

Milton Birnbaum
Center for Laser Studies, University of Southern California
University Park, DRB 17
Los Angeles, CA 90089-1112

26 May 1992

This document has been approved for public release and sale; its distribution is unlimited.

92 6 01 150

92-14497

SUMMARY AND CONCLUSIONS

The primary objective of this program involved the development of diode pumpable sources which could serve as the driver for a mid IR optical parametric amplifier. The present state-of-the-art is the diode-pumped Q-switched Nd:YAG at 1.06μ. The development of longer wavelength drivers was mandated by the need for improved efficiency in mid IR OPO's. The most promising candidate laser appeared to be the Er:YAG room temperature laser at 1.64μ. The development of diodes operating at the required pump wavelength for this laser indicated that diode pumping was feasible. The work performed utilized an Er:glass laser at 1.535μ as a pump souce. Characterization of Er:YAG laser action with this pump source can be used to model the diode pumped version of this laser.

Efficient laser operation of Er:YAG over an Er concentration of 0.5 to 4% at room temperature was demonstrated for the first time. Er:YAG laser action was achieved with absorbed inputs as low as 8 mJ and slope efficiencies approaching 50% were observed. The results obtained are summarized in Appendix 1, to be published in the proceedings of the Advanced Solid State Laser Conference held in Santa Fe, N.M., Feb. 17-19, 1992. In short, the Er:YAG laser at 1.64μ has been shown to posess the laser performance which makes it a promising candidate for development as a driver the an efficient mid-IR OPO.

Accesion For	
NTIS CRA&I	✓
DTIC TAB	[ ]
Unannounced	[ ]
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

Statement A per telecom
Robert Bachman
ONR/Code 1423
La Jolla, CA 92093-0234

NWW 6/22/92

ROOM TEMPERATURE 1.644 MICRON Er:YAG LASERS

Kalin Spariosu and Milton Birnbaum
Center for Laser Studies
University of Southern California
University Park, DRB 17
Los Angeles, CA 90089-1112
Phone: (213) 740-4230
Fax: (213) 740-8158

ABSTRACT

Room temperature Er:YAG (0.5, 1, 2 and 4%) lasers at 1.644μ were demonstrated by pumping with an Er glass laser at 1.535 μ. An end pumped arrangement was utilized simulating diode laser pumping. The characteristics of these low threshold and efficient lasers are described.

INTRODUCTION

The Er:YAG laser is a potentially useful eye-safe laser with numerous applications. We report the development of low threshold, efficient, room temperature Er:YAG lasers at 1.644μ. An Er:glass laser was used in an end-pumping arrangement which simulates diode pumping at 1.535 μ and, therefore, can be utilized to model the performance of diode-pumped 1.644 μ Er:YAG lasers.

The 1.64μ transition in Er, $^4I_{13/2}$ to $^4I_{15/2}$ had previously been studied using 0.4% Er, 5% Yb:YAG at 300 K with flash-lamp excitation [1]. This laser was found to have a high threshold and poor efficiency. Killinger [2] using a 1.47 μ F^+ - center laser pump, achieved 1.644μ Er:YAG laser operation at 77 K. The high threshold and low efficiency obtained were attributed to upconversion processes including the well known two-ion cooperative excitation process [3, 4]. Subsequently, Huber, et. al., [5] achieved room temperature CW operation of Er:YAG at 1.64μ by pumping with a krypton ion laser at 647.1 μm. A slope efficiency of 12.7 percent was obtained. Er concentrations in the range of 0.5 to 2 percent were utilized in order to minimize upconversion losses.

The commercially developed Er:glass laser [6,7,8] which incorporated Yb for sensitization, operates on the same transition. It is, in fact, a laser of this type [8] operating at 300 K at a wavelength of 1.535 μ on the $I_{13/2}$ to $I_{15/2}$ transition which was used as the pump source in these studies and in the work of ref [3].

Er:YAG LASER CHARACTERIZATION

The experimental arrangement for characterization of the 1.644μ Er:YAG laser is shown in Fig. 1. In order to clearly separate the Er:YAG laser output at 1.644μ from the stronger 1.535μ Er:glass pump a notch filter and a 1/4 m monochromator was used. The latter was used for wavelength determination of the Er:YAG lasers. The energy level diagram of Fig. 2 shows the pump transition and the laser transition of the Er:YAG lasers studied.

Laser action was obtained at 300 K with 0.5, 1, 2 and 4% Er:YAG crystals each approximately 1 cm in length with ends polished flat and parallel and uncoated. Typical results for the 0.5%, 1%, 2% and 4% Er:YAG crystals are shown in Figs 3a-3d. In case of the 4% Er:YAG crystals only a short burst of laser output was obtained (additional studies are in progress). The Er:glass laser pump pulse was approximately 1.5 ms in duration and laser action of the Er:YAG crystals occurred for durations as long as 1.2 ms and ceased at pump intensities about 0.1 that corresponding to the initiation of laser action.

Given the fast response time of the Er:YAG laser, it is expected that in the laser regime, the Er:YAG laser emission spikes will occur in time coincidence with the glass laser pump spikes. This behavior is shown in Fig. 4, redrawn from the oscilloscope traces for clarity. The shorter duration of the output pulses of the Er:YAG laser compared to those of the Er:Glass laser is in accordance with their respective photon cavity decay times.

The 3-level Er:YAG pumped from the ground state manifold of levels to the $^4I_{13/2}$ level provide a relatively simple system for analysis. For example, measurements of the reduced absorption or "bleaching" resulting from depletion of the ground state population and creation of a large population in the $^4I_{13/2}$ level showed that

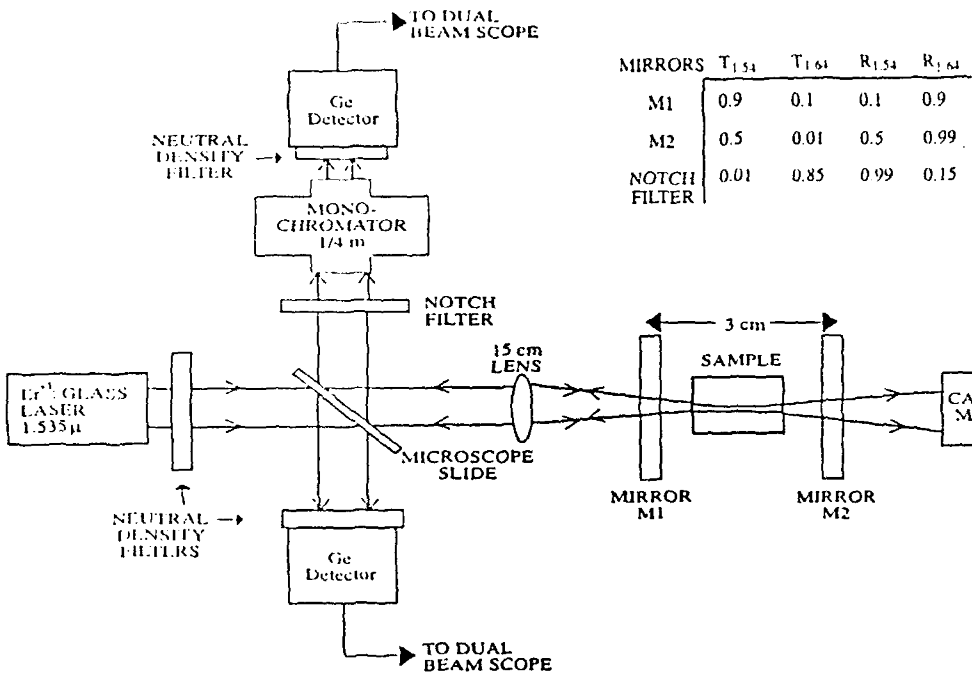
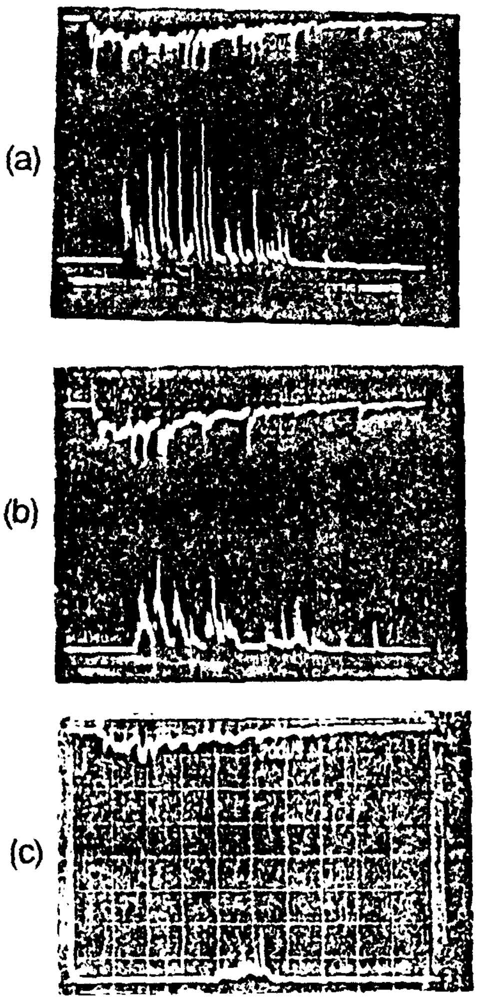


Fig.1. Experimental arrangement used for measurement of 1.644μ Er^{3+}:YAG laser characteristics.



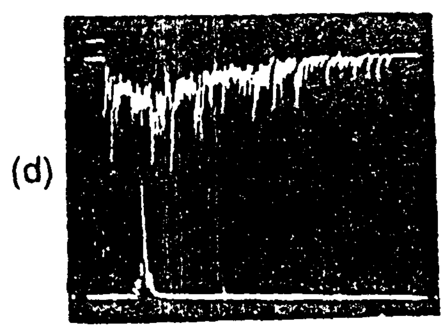


Fig.3. (a-d). 1.54μ pump signals (top traces) for 0.5(a), 1.0(b) and 2.0(c) and (d) % Er^{3+}:YAG; 1.644μ lasing signal (bottom traces).

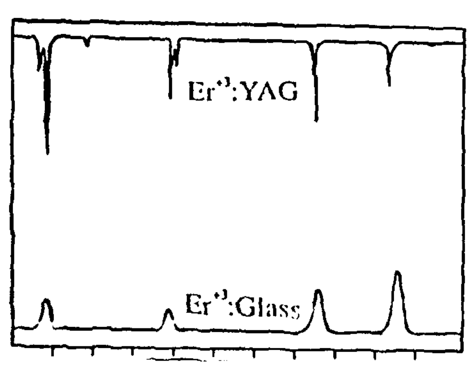


Fig.4. Time resolved 1.644μ lasing (top trace) with the corresponding (time coincident) 1.535μ pump pulses (bottom trace); 10μs/div.

population inversion between the $^4I_{15/2}$ and $^4I_{13/2}$ levels could be readily achieved. Laser action was observed and studied (see Fig. 3). The threshold for laser action is given approximately by

$$R_1 R_2 \exp 2L(\Delta n\sigma - \delta) \approx 1 \qquad (1)$$

where R_1 R_2 are the mirror reflectivities; Δn, the population inversion; σ, stimulated emission cross-section; L, length of the laser crystal; and, δ, additional losses. δ could also include a concentration dependent term to account for upconversion losses.

In order to estimate the inversion (Δn) from the absorbed energy (up to the time of laser action), knowledge of the focussed beam diameter is required. This was determined by measurement to be approximately 250 μ. The spiked output of the Er:glass laser permitted only a rough estimate of the pump energy absorbed to reach threshold for the 0.5, 1%, 2% and 4% samples. The absorbed 1.535 μ energies were respectively, 8 mJ, 10 mJ, 14 mJ and 23 mJ. Relative to the 0.5% Er:YAG the threshold values were 1,1.2, 1.7 and 2.9. The values predicted by Eq. 1 were 1.0, 1.4, 2.1, and 3.4. The computed threshold values were in reasonable agreement with the measured values. Work is in progress to clarify these and other features of our Er:YAG lasers.

Cooperative upconversion losses in 0.5 to 4% Er:YAG were estimated utilizing the theory and experimental results of Ref. 9 (for 10% Er:YAG, an upconversion coefficient, α_1, of 2.5 x 10^{-17} cm^3 s^{-1} was found). Our estimates indicated that for 0.5 to 1% Er:YAG upconversion losses should be negligible, small for 2% Er:YAG, and could be appreciable for 4% Er:YAG.

Er:YAG (0.5, 1, 2 and 4%) lasers at 1.64 μ were characterized at 300 K when end pumped by an Er:glass laser at 1.535 μ. Slope efficiciencies as high as 50% were obtained with the 0.5% Er:YAG. Low threshold operation was obtained which is indicative of the feasibility of diode pumped operation.

The support of this research by the U.S. Air Force Geophysical Laboratory is gratefully acknowledged.

REFERENCES

1. K. O. White and S. A. Schleusener, "Coincidence of Er:YAG Laser Emission with Methane Absorption at 1645.1 nm", Appl. Phys. Lett. 21 (9) 1 Nov. 1972, p. 419-420.

2. D. K. Killinger, "Phonon-assisted Upconversion in 1.64 μm Er:YAG Lasers", LEOS, Digest of Tech. Papers, 26 April - 1 May 1987, p. 240.

3. S. A. Pollack, D. B. Chang and N. L. Moise, "Upconversion-pumped Indrared Erbium Laser", J. Applied Phys., vol. 60, No. 12, 15 Dec. 1986, pp. 4077-86.

4. S. A. Pollack, D. B. Chang, M. Birnbaum and M. Kokta, "Upconversion-Pumped 2.8-2.9 μm Lasing of Er^{3+} Ion in Garnets", to be published in J. Appl. Phys.

5. G. Huber, E. W. Duczynski and K. Petermann, "*Laser Pumping of Ho-, Tm-, Er-doped Garnet Lasers at* Room Temperature", IEEE J. Quant. Electr. Vol. 24, No. 6, June 1988, pp 920-924.

6. E. Snitzer and R. F. Woodcock, "Yb^{3+} - Er^{3+} Glass Laser", Appl. Phys. Lett. 6, 45, 1965.

7. E. Snitzer, R.F. Woodcock, and J. Segre, "Phosphate Glass Er^{3+} Laser", IEEE J. Quant. Electr. QE-4, 360, 1968.

8. Kigre, Inc. Hilton Head Island, SC. A QE-7S Er:phosphate laser glass rod courtesy of Kigre, Inc. was used in the tests described in this paper.

9. V. I. Zhekov, T. M. Murina, A. M. Prokhorov, M. I. Studenikin, S. Georgescu, V. Lupei, and I. Ursu, "Cooperative Process in $Y_3Al_5O_{12}$:Er^{3+} Crystals", Sov. J. Quant. Electron. Vol. 16, No. 2, Feb. 1986, p. 274-6.

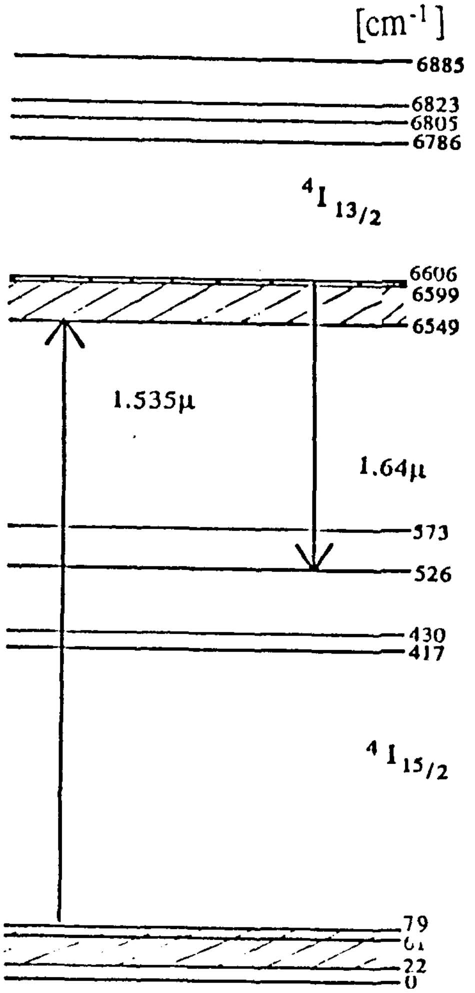


Fig.2. Energy level diagram of Er^{3+}:YAG showing the pump and laser lines.